A RESEARCH ON APPLYING THE GENETIC ALGORITHM TO REPLACE THE HILL-CLIMBING METHOD IN TRANSYT-7F MODEL

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abstract: The Genetic Algorithm is a kind of optimal algorithms developing recently. It is not only suitable to deal with complex nonlinear optimization problems, but also able to seek the so-called global optimum or approximate optimum. Generally speaking, TRANSYT Model is one of the most important and popular network signal timing design models in the world. It comprises a traffic flow simulation model and another signal timing optimization model. In this study, we tried to replace the optimization model of Hill-Climbing Method in TRANSYT-7F to that of the Genetic Algorithm. Besides, we set up three road networks configuration with different sizes and level of traffic flows are proposed to be used in the sensitivity analysis. Finally, a real network case study is engaged to achieve similar results with significant performance.

1. INTRODUCTION

There were existing two problems in the research of traffic signal system network timing model for a long time. One was the limitation of computer's calculation speed. Computers could not figure out the optimal signal timing of a large-sized network in a short time. The other was that we could not effectively utilize the skills of optimum algorithms in the mathematical programming theory. It was because the traffic network timing optimization was a nonlinear problem, and so far we were lacking a set of effective algorithmic logic to obtain the so-called global optimum. Therefore, signal timing patterns of any practical traffic network generated in terms of off-line method. That is, in terms of signal timing design software, to input network geometric information in advance to obtain the optimal signal timing patterns, then, to install timing plans in the traffic signal system to control the traffic flow in the network.

The Genetic Algorithm was a kind of optimal algorithms developing recently. It was not only suitable to deal with complex nonlinear optimization problems, but also able to seek the so-called global optimum or approximate optimum. Besides, its model operation structure was also fit for the application of computer‘s parallel processing. Based on the above merits, if we applied it to the network timing solution of computerized traffic signal system, we could get a optimal signal timing pattern that might be more effective than what we got from most of the other existing signal timing design softwares.

TRANSYT-7F Model was the most popular one of the network signal timing design softwares. In this study, we hoped, through understanding the Genetic Algorithm and analyzing its characteristics, to revise the optimization model of the Hill-Climbing Method to that of the Genetic Algorithm. Besides, because there were varied parameters when we applied the Genetic Algorithm, such as PI degrees in fitness function, crossover method, rate of match, preventing incest, probability of mutation, we needed simulation analyse tests to make suitable hypothesis. Therefore, we prepare three simulation networks with three different sizes and flows, which were 2x2, 3x3, and 4x4, to be used in sensitivity analysis and case study. The latter was divided into a simulation network case and a practical network case.

2. THE ESTABLISHMENT OF MODELS

The Genetic Algorithm was a kind of new optimal logic. When it was applied in various problems to seek their solutions, it was necessary to adopt some proper changes according to the problems‘ characteristics, though the general ideas were identical. When the Genetic Algorithm was applied, particularly, the solutions had to be changed into chromosomal structure so as to accord with the operation in process of genetic deduction, such as crossover, mutation, etc. Therefore, before utilizing the Genetic Algorithm to solve network signal timing problems, we should have better understanding of the problems' characteristics.

Also, we utilized the original traffic flow simulation model of TRANSYT-7F to obtain the measure of effectiveness (MOE). Therefore, the variable‘s form of timing equation in TRANSYT-7F had important effects to the chromosomal structure of TRANSYT-GA we had established in this study.

2.1 Relations between TRANSYT-GA and TRANSYT-7F

In network signal timing design, in order to maintain the timing relations of each adjacent intersection in the network, there were common cycle and fixed offset. Every intersection had individual timing split and phasing sequence. Generally, both cycle length and split had a reasonable range. A common cycle plus individual intersection‘s time split, offset, and phasing sequence constituted the main characteristics of the network timing pattern. In TRANSYT-7F, common cycle, timing split, and offset all could be optimized, except phasing sequence. In the original TRANSYT-7F, common cycle was an independent variable, but timing split and offset were decided by the variable NBIAS (D1, D2). Both D1 and D2 were integers, and D2 meant the intersection number. The whole structure of TRANSYT-7F model was shown in Figure 1. TRANSYT-GA established in this study employed GA as the optimization model and the substitution for Hill-Climbing method of TRANSYT-7F, as shown in Figure 2.

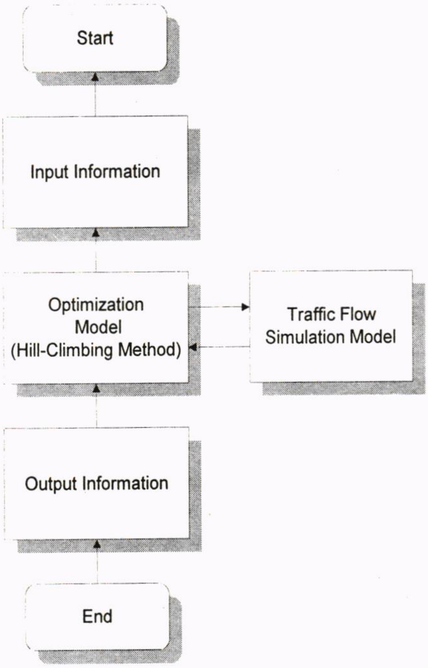

Fig. 1 - Block Structure of TRANSYT-7F

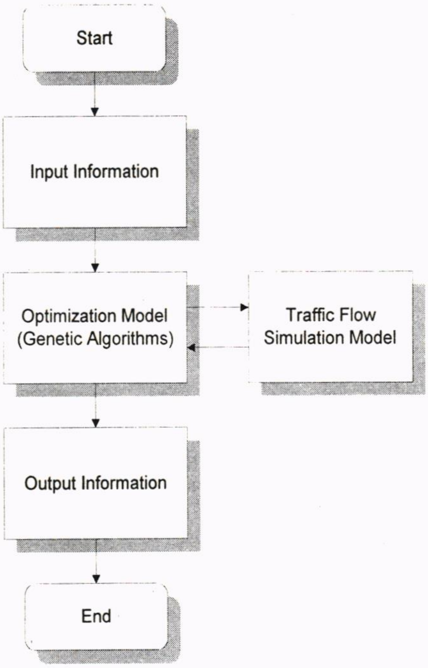

Fig. 2 - Block Structure of TRANSYT-GA

The detailed structure of the Genetic Algorithm optimization model was shown in Figure 3. First, we should assume rate of match, preventing incest, probability of mutation, limitation of computer's execution time, etc. in this model so as to produce the chromosomal preliminary value in population and set up generational alternations and population continual generations. We got the idea of population continual generations from that, in process of generational alternations, natural disaster and manmade calamity probably occurred once every several generations, and it caused profuse death of chromosomes of population and produced new ones afresh. Its purpose was to prevent chromosomal deadlock (unanimousness). This study set up that natural disaster and manmade calamity occurred every five generations. Regarding the generation alternations in genetic deduction, first, we calculated the total match chromosomal number according to the rate of match, then, under the conditions of preventing incest, used the fitness as probability to choose match chromosomes, proceeded crossover, mutation, and produced new chromosomes of the match one. Finally, we calculated new chromosomes' fitness and decided if the new chromosomes could substitute for the old ones. Within the substitution duration, high fitness chromosomes would substitute for the low ones. We did not repeat the two actions until they acted pursuant to the law of generational alternations, then, output the chromosomes with superior fitness and put an end to this alternation.

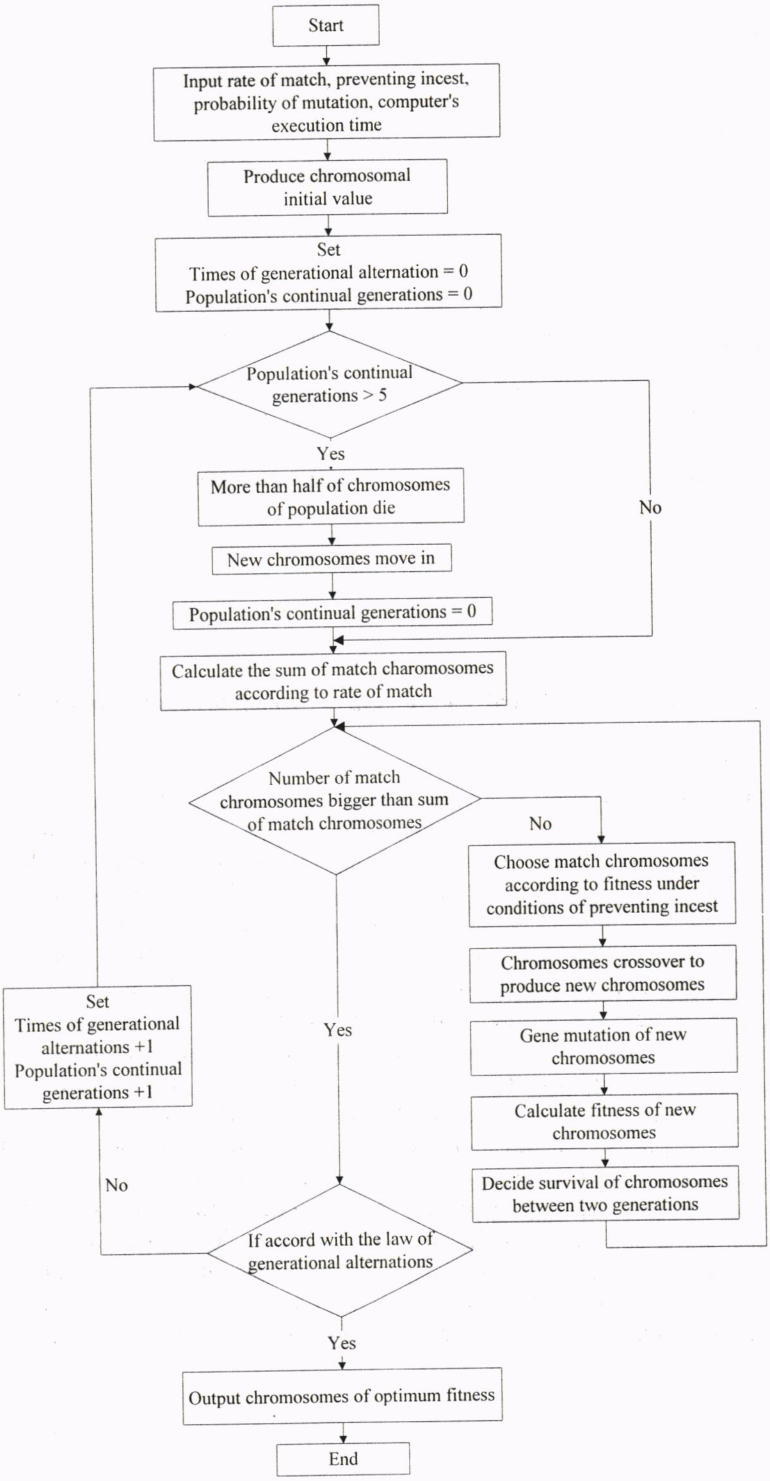

Fig. 3 - TRANSYT-GA Process of Genetic Deduction

2.2 Chromosomal Expression in Network Timing Pattern

Network timing pattern was defined as chromosomal structure of binary string The so-called binary string was a string composed of "0" and "1". Its practical structure and definition were shown as follows:

01010101	00	10110100	10001010	. . .	10	10101010	10110101	. . .
Common Cycle	Phasing Sequence	NBIAS (1, 1)	NBIAS (2, 1)	. . .	Phasing Sequence	NBIAS (1, 1)	NBIAS (2, 1)	. . .

Intersection 1 | Intersection 2

- Common cycle took 8 bits
- Phasing Sequence took 2 bits
- NBIAS (x, x) took 8 bits
- Offset of Intersection N = NBIAS (1,N) - NBIAS (1, M) of Master-controlled Intersection M
- Phase M's Length of Intersection N = NBIAS (M+1, N) - NBIAS (M, N) + Phase M's Length of Amber and All-red Period - Phase M + 1's Length of Amber and All-red Red Period

2.3 Operations of Genetic Deduction and Evolution

The operations aiming directly at genetic deduction and evolution included: calculation of fitness, choices of match, crossover methods, ways of mutation, disposals of species deadlock, disposals of limitation, judgments of ending conditions, etc. This study operated as follows:

(1) Calculation of Chromosomal Fitness

In TRANSYT-GA, fitness represented the fluency of traffic flow in network with optimal timing pattern. Because the performance index (PI) in traffic flow simulation system represented negative effect, we defined chromosomal fitness value as the inverse ratio to m degree of system PI value resulted from a set of network timing pattern input traffic flow simulation model, and PI value was the lower the better. That is , the higher performance index meant that, in systems, the traffic flow was more fluent, and the vehicle's number of stops and delay were lower, while the lower performance index meant that, in systems, the traffic flow was less fluent and vehicle's number of stops and delay were higher. Fitness calculation in TRANSYT-GA Model was shown as equation 1:

$$Chromosomal\ Fitness = \frac{1}{(PI)^n} \qquad (1)$$

$$PI = \sum_{i=1}^{n} (Di + K \times Si)$$

Di: Delay in intersection i (vehicle - hour / hour)
Si: Number of stops in intersection i (number of stops / hour)
K: The weighted coefficient between a vehicle stop and vehicle delay

PI: System Performance index
n: Real number bigger than 0

(2) Choices of Chromosomal Match

In biological population, the individual with more competence possessed stronger competition ability, and it was more possible to have a group of spouses. In mathematics, every chromosome in the population represented the solution within the problem's seeking solution space. Solutions were either good or bad. Chromosome with higher fitness meant the solution was better, and chromosome with lower fitness meant the solution was worse. According to the biological law of survival of fittest, the Genetic Algorithm disguised the chromosome with higher fitness as the stronger with high crossover ability, and gave it more opportunity to mate. Users could freely set up the size of population and height of match rate. Size of population times rate of match were the number that chromosomes proceeded crossover in each generation. The procedure of producing spouse in TRANSYT-GA was as follows:

a. First, sum up all the chromosomal fitness, as equation 2.

$$Sumfitness = \sum_{i=1}^{n} Fitness(i) \tag{2}$$

- Fitness (i) was the fitness value of chromosome i
- Sumfitness was the sum of fitness value of all chromosomes

b. Utilize stochastic random-number generator of uniform distribution ranged between [0,1] to produce a random number, then, time Sumfitness to obtain:

$$Rand = Random\ (10) \times SumFitness$$

- Random (10) was a random-number generator of uniform distribution, the seed was 10. Rand was a set of numbers ranged between [0, Sumfitness]

c. Produce chromosomes by choosing match. The logic was as follows:

```
PartSum = 0.0
j = 0
Do
j = j + 1
PartSum = PartSum + Fitness (i)
While (PartSum ≥ Rand)
Selected = j
```

- PartSum was the sum of a part of fitness
- j was an integer variable
- Selected was the chromosomal number we had chosen

d. Suppose that match should proceed with two chromosomes. Repeat steps b and c to produce two different chromosomes, then, to mate with each other.

(3) Method of Crossover

After choosing the match, chromosomes had to mate so as to obtain descendants. This study supposed crossover probability was 100%, and had two descendants certainly. So far the crossover methods raised were one-point crossover, two-point crossover, and uniform crossover. We tested these three crossovers respectively, then, discussed their good and bard qualities to be the basis of adoption for this study.

a. One-Point Crossover

The so-called one-point crossover was to take a switch-point in a pair of chromosomes in terms of stochastic way, then, exchange genes after the switch-point. In the following example, we supposed the switch-point was 3, the length of chromosome was 10 units, and the situations before and after crossover were as follows:

Chromosomes Before Crossover (Paternity)
1011010111
0110101100

Chromosomes After Crossover (Descendant)
101**0101100**
011**1010111**

b. Two-Point Crossover

The so-called two-point crossover was to take two switch-points in a pair of chromosomes in terms of stochastic way, then, exchange genes within the two switch-points. In the following example, we supposed the switch-points were 3 to 7, the length of chromosome was 10 digits. The situations before and after crossover were as follows:

Chromosomes Before Crossover (Paternity)
1011010111
0110101100

Chromosomes After Crossover (Descendant)
101**0101111**
011**1010100**

c. Uniform Crossover

The so-called uniform crossover was to produce a mask in terms of stochastic way, and utilize the unit "0" or "1" in the mask to decide if the units in chromosomes could mate with each other. If the unit was "1", we did the match, and if it was "0", we did not. For example, if the chromosomal length of a gene was 10 units, the situations before and after crossover were as follows:

Chromosomes Before Crossover (Paternity)
1011010111
0110**10**1**100**

Mask: 1000110101

Chromosomes After Crossover (Descendant)
0011100110
1110011101

(4) Mutation

Mutation meant that extraordinary transmutation happened to gene after crossover. As for mutation in this study, we changed the original value of some genes in chromosomes after crossover into contrary value, and the choice of mutation gene in chromosomes was stochastic. The way was as follows:

```
Location of Gene Mutation in Chromosome = Chromosomal Length * Random (10)
Probability of Gene Mutation = Random (10)

IF
    Probability of Gene Mutation ≤ Probability of Mutation Given by Users
THEN
    Gene mutation happened,
ELSE
    Gene mutation did not happen.
END IF
```

For example, a gene's chromosomal length was 10 digits, we supposed the mutation gene was located at the fourth digit, and after mutation, the gene at the fourth digit changed from "1" to "0".

Chromosomes Before Mutation (Paternity)
1011000101
-

Chromosomes After Mutation (Descendant)
1010000101
-

(5) Disposals of Species Deadlock

Since most of the chromosomes in population converged around a certain value, and that slowed down evolution. Some documents named this situation "premature converge". In mathematics, around the optimum solution, the incline rate was smaller, and the quality of solutions was less. Therefore, when we searched around the optimum solution, there must be a phenomenon of slower converge. As for disposals of deadlock, this study adopted a two-step method. The first step was to limit two similar chromosomes' crossover in term of preventing incest. This study set up a standard of preventing incest. When the mating chromosomes violated the standard, we forbad their match and directed them to choose a new mate. It was allowed only if this chromosome had continually chosen mates more than n times (n = the size of population - one). The next step was to bring in foreign species, and proceeded the second evolution in terms of crossbreeding. In disposal, we set up that, after population passed k generational alternations, there was a disaster, and the population died more than half. Foreign populations moved in to make up the size of original population. To do this, we produced new chromosomes moving in by probability. And, in the disaster, the chromosomes with highest fitness would not die, but the others would die possibly. The main reason we used these two steps to dispose the deadlock problem was that, in the generational alternations, chromosomes became unanimous gradually. Preventing incest was a prevention before species deadlock happened, while bringing in foreign species was a reaction after that happened. The population restored varieties of chromosomes after bringing in foreign species. Therefore, the searching direction in the optimization procedure of the Genetic Algorithm became wider.

(6) Conditions of Converge

As to the optimization of nonlinear mathematical programming problems, it was difficult to define effective conditions of converge so as to judge if the global optimum was found. So far, there were no documents raising any effective conditions of converge, not to mention stochastic search in the Genetic Algorithm Model. In the TRANSYT-GA Model, there were two situations to stop the optimization operation. One situation was when the optimum fitness never changed for n generations continually (n was given by users), the optimization terminated. The other was to limit the execution time of optimization. When the execution time was more than users gave, stop the optimization operation.

3. ANALYSIS OF PARAMETER

Analysis of parameter mainly included four parts: the first part was analyzing the methods of chromosomal crossover during genetic deduction; the second was analyzing rate of match and preventing incest of population and probability of mutation in the chromosomes; the third was analyzing the fitness function; the last was discussing the effectiveness of K value in performance index.

3.1 Analysis of Chromosome Crossover Methods

As the aforesaid, there wee three kinds of chromosomal crossover methods: one-point crossover, two-point crossover, and uniform crossover. When progressing the experiment of effectiveness of chromosomal crossover methods to converge performance index, rate of match, preventing incest, and probability of mutation all affected the converge procedure. Aiming at this problem, this study focused on seeking the optimization of objective function, and we hoped when we compared these three chromosome crossover methods, all the parameters of rate of match, preventing incest, and probability of mutation were at an appropriate value. For this reason, before analyzing chromosome crossover methods, we should test rate of match, preventing incest, and probability of mutation, respectively, and use the results as parameter in practical compare. The performance index of one-point crossover, two-point crossover, and uniform crossover change with the operating time, whose relations were shown in Figures 4, 5, and 6. The results showed that, most converge of one-point crossover concentrated within the first 119 seconds, what of two-point crossover concentrated within the first 165 seconds, and what of uniform crossover concentrated within the first 490 seconds. Therefore, two-point crossover converge was the fastest.

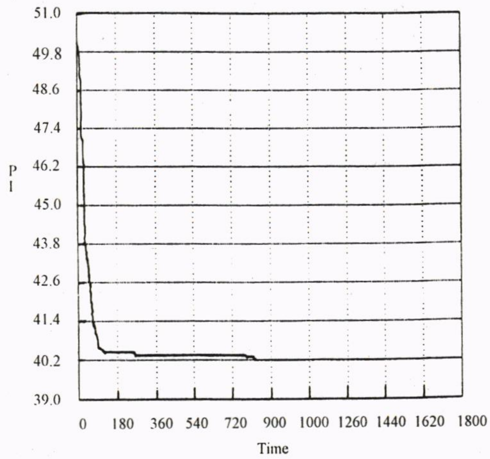

Fig. 4 - Relations between One-Point Crossover PI and Execution Time

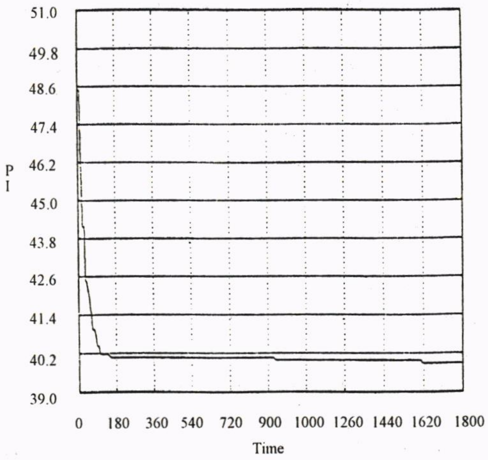

Fig. 5 - Relations between Two-Point Crossover PI and Execution Time

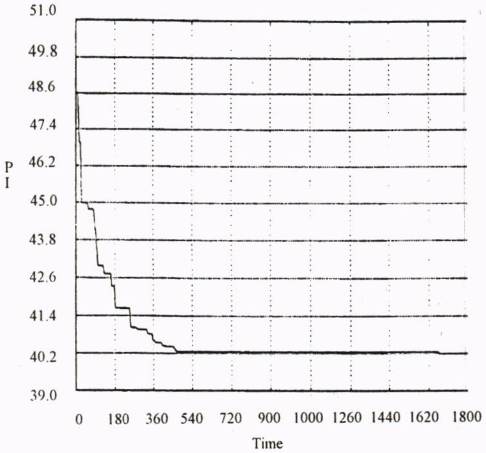

Fig. 6 - Relations between Uniform Crossover PI and Execution Time

3.2 Optimum Parameter Combinations of Two-Point Crossover

In the Genetic Algorithm, all rate of match, preventing incest, and probability of gene mutation could affect converge speed and quality. This study divided rate of match into 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, then, found out respectively optimum preventing incest, probability of mutation, and the biggest performance improvement percentage in terms of signal-factor test. The results were shown in Table 1. From the results we learned that when rate of match was 0.3, 0.5, 0.6, and 0.7, TRANSYT-GA performance index improved over 12% than TRANSYT-7F, what's more, the most concentrated around rate of match 0.6. Therein, with the same installed information, system performance index obtained by TRANSYT-7F Hill-Climbing optimization was 45.37.

Table 1 - Parameter Optimum Combination

Rate of Match	Preventing Incest	Mutati Probability	Performance Index	Percentage Improvement
0.1	1.0	0.5	40.48	10.95
0.2	0.6	0.0	40.12	11.57
0.3	0.6	0.0	39.80	12.28
0.4	0.5	0.1	40.11	11.59
0.5	0.8	0.0	39.88	12.10
0.6	0.7	0.5	39.80	12.28
0.7	0.8	0.0	39.80	12.28
0.8	0.5	0.1	40.06	11.70
0.9	0.6	0.3	39.97	11.90
1.0	0.6	0.3	40.06	11.70

3.3 Fitness Function

In this study, chromosome fitness function was defined as system performance index function, as equation 1. The higher the system performance index was, the lower the fitness was. On the other hand, the lower the system performance index was, the higher the fitness was.

Higher fitness chromosomes in population, within the generation alternation duration, were chosen to be match chromosomes more probably. When n value in equation 1 was bigger, the more differences of fitness value were caused by varied system performance index. Because the process of the Genetic Algorithm obeyed the law of survival of fittest, match behavior would concentrate within high fitness chromosome area. When n value was big, match chromosomes would concentrate more increasingly within better fitness area. For converge performance index, it would not be good hat match chromosomes excessively concentrated within some small area, because, progressing within a small area, there would not be many differences between new chromosomes produced in chromosomal match, crossover, and mutation. For evolution, it was not easy to achieve outstanding development. Aiming at the sizes of n value, this study utilized 3x3 simulation network in different traffic flows, and set up n value as 0.5, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, and 10.0 to test and compare converge performance index within 570 seconds, respectively. The results were shown in Table 2 and Figures 7, 8, 9, and 10 From the results we learned the performance index after converge was lower when n was 1. Therefore, we defined fitness function as equation 3.

$$Fitness = \frac{1}{PI} \tag{3}$$

Table 2 - Converge PI under Different n Value

n \ Flow Level	70%	80%	90%	100%
0.5	23.76	29.57	34.07	40.13
1.0	23.55	28.56	33.81	39.80
2.0	24.51	28.66	34.88	40.05
3.0	23.77	28.40	35.09	40.57
4.0	23.76	28.68	34.64	40.90
5.0	23.94	29.58	35.17	40.79
6.0	23.75	28.56	34.37	40.39
7.0	24.40	29.70	34.09	40.61
8.0	24.57	29.48	34.97	41.34
9.0	24.64	29.38	34.88	41.05
10.0	24.56	29.29	35.13	41.12

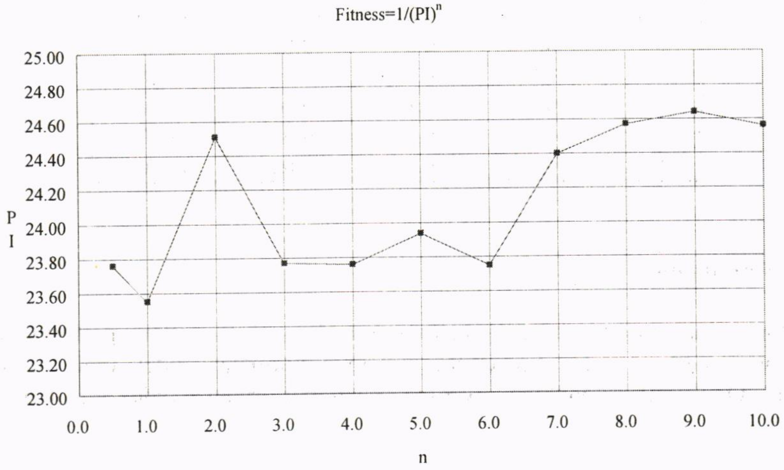

Fig 7 - Trend of Different n Value under 70% Flow Level

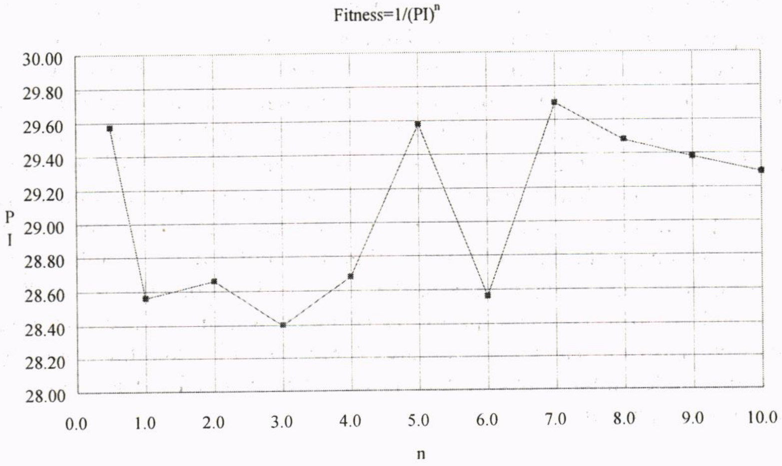

Fig 8 - Trend of Different n Value under 80% Flow Level

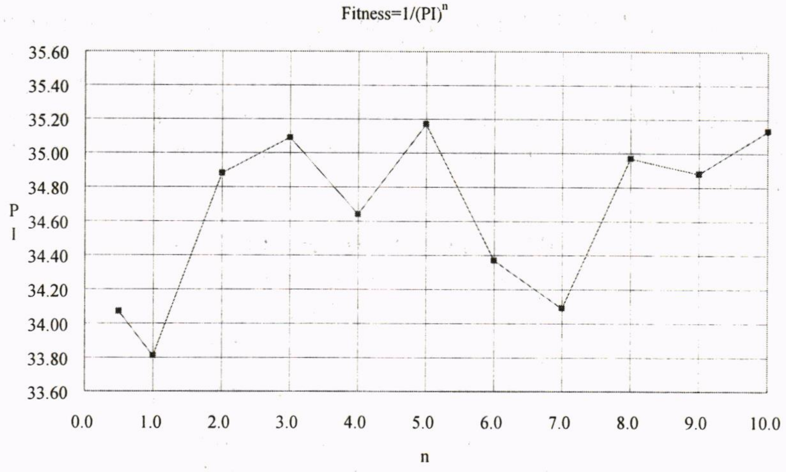

Fig 9 - Trend of Different n Value under 90% Flow Level

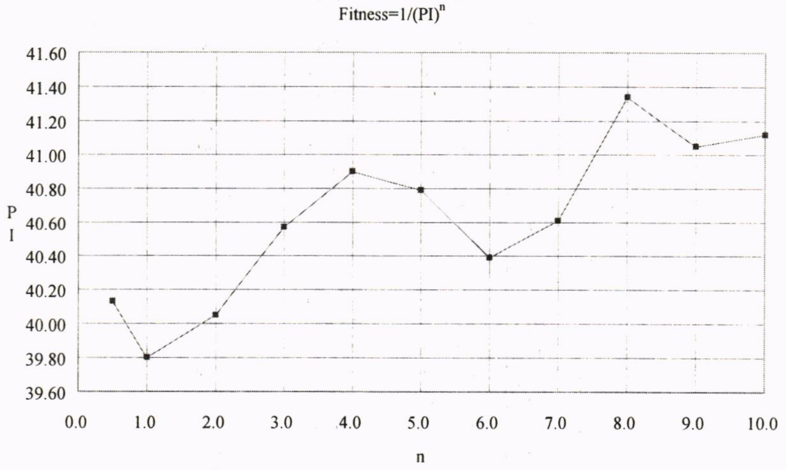

Fig 10 - Trend of Different n Value under 100% Flow Level

3.4 Effectiveness of K Value

K value was a relative weighted coefficient of vehicle delay and number of stops in system performance index. Different K values would affect the ratio of delay and number of stops in performance index. The bigger K value meant the higher the importance of waiting times was, while the smaller K value meant the higher the importance of delay was. Generally speaking, K value ranged from -1 to 10,000. When K value was -1, equation would use minimized fuel consumption as objective to design signal timing pattern. In order to investigate the effectiveness of K value‘s changes to the improvement of performance index, this study tested 3x3 network under traffic flow level 100%, fixed computer execution time of TRANSYT-GA as 570 seconds, and the test range of K value was between -1 and 500. The results were listed in Table 3 and Figure 11. From the trend of Figure 11, we could find when K value was smaller than or equal to 100, the result of TRANSYT-GA was better than what of TRANSYT-7F, while between 100 and 200, the result of TRANSYT-7F was better. When K value was bigger than 200, there were little differences between the results of TRANSYT-GA and TRANSYT-7F. Generally speaking, K value should set up between 0 and 100, the previous experimental value of TRRL was the same, too.

Table 3 - PI under Different K Value

K value	PI		
	TRANSYT-GA	TRANSYT-7F	Improvement Percentage
-1	39.80	45.37	12.28%
0	26.91	28.17	4.47%
20	58.17	65.23	10.82%
40	89.02	99.89	10.88%
60	120.15	134.56	10.71%
80	151.96	169.27	10.23%
100	183.10	183.63	0.29%
120	214.36	210.43	-1.87%
140	243.71	236.62	-3.00%
160	276.68	262.89	-5.25%
180	309.31	288.31	-7.28%
200	339.80	314.48	-8.05%
220	341.09	342.40	0.32%
240	366.13	366.81	0.19%
260	391.91	392.98	0.27%
280	420.75	419.15	0.38%
300	444.51	447.32	0.63%
320	469.32	173.59	0.90%
340	499.15	487.65	-2.36%
360	524.81	526.74	0.37%
380	549.66	549.98	0.06%
400	572.74	576.15	0.59%
420	607.01	602.28	-0.79%
440	622.51	631.17	1.37%
460	657.96	656.57	-0.21%
480	680.32	680.53	0.03%
500	704.85	708.50	0.52%

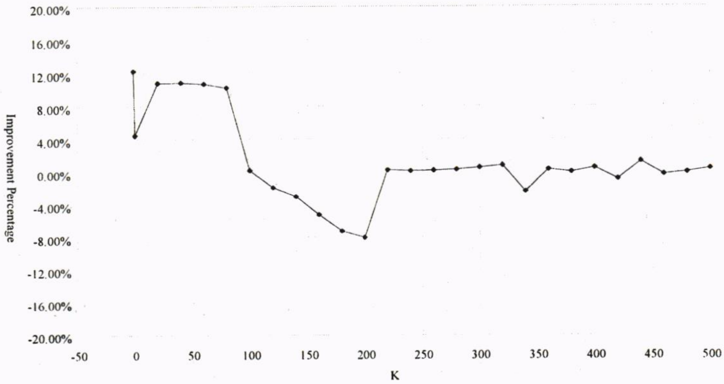

Fig. 11 - Improvement Percentage under Different K Value

4. CASE STUDY

4.1 Case Study in Artificial Network Test

The artificial Simulation networks included three different sizes of network, 2x2, 3x3, 4x4. Therein, number of vehicle lanes, traffic flow, and length of road segment were produced randomly, and the results figured out were shown in Tables 4, 5, and 6.

Table 4 - Results Calculated from 2x2 Artificial Network

Method	Flow	Rate of Match	Preventing Incest	Rate of Mutation	PI	Improvement Percentage	Execution Time (Sec)	PI of TRANSYT-7F
T7F	80%	-	-	-	48.16	-	23.23	48.16 (0.00%)
TGA	80%	0.5	0.8	0.1	44.91	6.75%	570.00	46.65 (3.14%)
TGA	80%	0.6	0.7	0.5	44.85	6.87%	570.00	45.54 (5.44%)
TGA	80%	0.7	0.8	0.0	45.68	5.15%	570.00	45.80 (4.90%)
T7F	100%	-	-	-	64.62	-	23.17	64.62 (0.00%)
TGA	100%	0.5	0.8	0.1	60.79	5.93%	570.00	68.87 (-6.58%)
TGA	100%	0.6	0.7	0.5	60.52	6.34%	570.00	61.61 (4.65%)
TGA	100%	0.7	0.8	0.0	60.90	5.76%	570.00	62.30 (3.59%)
T7F	120%	-	-	-	137.13	-	23.17	137.13 (0.00%)
TGA	120%	0.5	0.8	0.1	136.28	0.62%	570.00	141.40 (-3.11%)
TGA	120%	0.6	0.7	0.5	135.98	0.84%	570.00	141.98 (-3.54%)
TGA	120%	0.7	0.8	0.0	135.40	1.26%	570.00	138.20 (-0.78%)

The results of case study in artificial network showed:

1. The improvement performance index converged form TRANSYT-GA and TRANSYT-7F at the highest and the lowest flows was smaller.
2. The size of network increased from 2x2, 3x3, to 4x4, that is, number of intersections increased from 4 to 9 to 16. But improvement of converge performance index did not gradually increase or decrease because of the changes of network sizes.
3. Under optimum parameters combination and rate of match 0.5, 0.6, and 0.7, there were little differences between improvements of converge performance index, but when rate of match was 0.6, universally it is better.
4. When execution time was long enough, converge performance index results of TRANSYT-GA were better than TRANSYT-7F, and the biggest improvement percentage was 17.6%.
5. Within the same converge time with TRANSYT-7F, comparing performance index of TRANSYT-GA with TRANSYT-7F, the improvement percentage was between 16.46% and -7.25.

Table 5 - Results Calculated from 3x3 Artificial Network

Method	Flow	Rate of Match	Preventing Incest	Rate of Mutation	PI	Improvement Percentage	Execution Time (Sec)	PI of TRANSYT-7F
T7F	50%	-	-	-	16.696	-	97.13	16.696 (0.00%)
TGA	50%	0.5	0.8	0.0	15.523	7.00%	570.00	15.382 (7.87%)
TGA	50%	0.6	0.7	0.5	15.197	9.00%	570.00	15.379 (7.89%)
TGA	50%	0.7	0.8	0.0	15.264	8.60%	570.00	15.707 (5.92%)
T7F	60%	-	-	-	20.761	-	92.46	20.761 (0.00%)
TGA	60%	0.5	0.8	0.0	19.312	7.00%	570.00	19.960 (3.86%)
TGA	60%	0.6	0.7	0.5	19.488	6.10%	570.00	19.488 (6.13%)
TGA	60%	0.7	0.8	0.0	19.588	5.70%	570.00	19.370 (6.70%)
T7F	70%	-	-	-	28.584	-	90.50	28.584 (0.00%)
TGA	70%	0.5	0.8	0.0	23.903	16.40%	570.00	23.880 (16.46%)
TGA	70%	0.6	0.7	0.5	23.548	17.60%	570.00	24.060 (15.87%)
TGA	70%	0.7	0.8	0.0	23.755	16.90%	570.00	24.219 (15.27%)
T7F	80%	-	-	-	32.560	-	87.94	32.560 (0.00%)
TGA	80%	0.5	0.8	0.1	28.450	12.60%	570.00	28.610 (12.12%)
TGA	80%	0.6	0.7	0.5	28.560	12.30%	570.00	- (-)
TGA	80%	0.7	0.8	0.0	28.820	11.50%	570.00	29.040 (10.82%)
T7F	90%	-	-	-	38.561	-	84.03	38.561 (0.00%)
TGA	90%	0.5	0.8	0.0	34.082	11.60%	570.00	34.386 (18.20%)
TGA	90%	0.6	0.7	0.5	33.810	12.30%	570.00	34.314 (11.01%)
TGA	90%	0.7	0.8	0.0	34.082	11.60%	570.00	34.578 (10.33%)
T7F	100%	-	-	-	45.370	-	81.97	45.370 (0.00%)
TGA	100%	0.5	0.8	0.1	40.420	10.90%	570.00	40.880 (9.89%)
TGA	100%	0.6	0.7	0.5	39.800	12.30%	570.00	40.920 (9.81%)
TGA	100%	0.7	0.8	0.0	39.800	12.30%	570.00	41.010 (9.61%)
T7F	110%	-	-	-	53.795	-	80.36	53.795 (0.00%)
TGA	110%	0.6	0.7	0.5	48.396	10.00%	1200.00	48.967 (8.97%)
T7F	120%	-	-	-	59.482	-	78.17	59.482 (0.00%)
TGA	120%	0.7	0.8	0.0	58.260	2.10%	1300.00	63.796 (-7.25%)
T7F	130%	-	-	-	75.030	-	76.54	75.030 (0.00%)
TGA	130%	0.6	0.7	0.5	69.915	6.80%	1400.00	73.971 (1.41%)
T7G	140%	-	-	-	85.288	-	74.43	85.288 (0.00%)
TGA	140%	0.6	0.7	0.5	84.651	0.70%	1500.00	87.988 (-3.17%)

Table 6 - Results Calculated from 4x4 Artificial Network

Method	Flow	Rate of Match	Preventing Incest	Rate of Mutation	PI	Improvement Percentage	Execution Time (Sec)	PI of TRANSYT-7F
T7F	40%	-	-	-	80.96	-	228.32	80.96 (0.00%)
TGA	40%	0.6	0.7	0.5	74.17	8.39%	1200.00	77.48 (4.30%)
TG7	60%	-	-	-	127.89	-	214.85	127.89 (0.00%)
TGA	60%	0.6	0.7	0.5	123.96	3.07%	1200.00	130.23 (-1.83%)
T7F	80%	-	-	-	183.95	-	213.55	183.95 (0.00%)
TGA	80%	0.6	0.7	0.5	170.55	7.28%	1200.00	181.21 (14.90%)
T7F	100%	-	-	-	242.95	-	202.09	242.95 (0.00%)
TGA	100%	0.6	0.7	0.5	234.00	3.68%	1200.00	257.16 (-5.85%)

4.2 Practical Network Case Study

The practical network information came from a traffic survey information within "Network and Arterial Signal Design Software T7F-T88 User's Manual", published by the Department of Transportation and Communication Management, National Cheng Kung University on December, 1988. It included four intersections of Chin-Hua Artery, Tainan City, eight intersections of San-Min Artery, Taichung City, and twelve intersections in road network of Keelung City. The results figured out were shown in Table 7, 8, and 9.

Table 7 - Results Calculated from Traffic Data of Chin-Hua Artery

Method	Flow	Rate of Match	Preventing Incest	Rate of Mutation	PI	Improvement Percentage	Execution Time (Sec)	PI of TRANSYT-7F
T7F	Low	-	-	-	27.25	-	0.25	27.25 (0.00%)
TGA	Low	0.5	0.8	0.1	23.72	12.95%	570.00	25.51 (6.37%)
TGA	Low	0.6	0.7	0.5	23.76	12.81%	570.00	25.51 (6.37%)
TGA	Low	0.6	0.7	0.1	23.72	12.95%	570.00	25.51 (6.37%)
TGA	Low	0.7	0.8	0.0	23.72	12.95%	570.00	25.51 (6.37%)
T7F	Medium	-	-	-	47.84	-	0.26	47.84 (0.00%)
TGA	Medium	0.5	0.8	0.1	42.58	10.99%	570.00	46.90 (1.87%)
TGA	Medium	0.6	0.7	0.1	42.50	11.16%	570.00	46.90 (1.87%)
TGA	Medium	0.7	0.8	0.0	42.50	11.16%	570.00	46.90 (1.87%)
T7F	High	-	-	-	128.47	-	1.35	128.47 (0.00%)
TGA	High	0.5	0.8	0.1	116.47	9.34%	570.00	116.47 (9.34%)
TGA	High	0.6	0.7	0.5	116.47	9.34%	570.00	116.47 (9.34%)
TGA	High	0.7	0.8	0.0	116.47	9.34%	570.00	116.47 (9.34%)

Table 8 - Results Calculated from Information of Sun-Min Artery

Method	Rate of Match	Preventing Incest	Rate of Mutation	PI	Improvement Percentage	Execution Time (Sec)	PI of TRANSYT-7F
T7F	-	-	-	233.21	-	0.51	233.21 (0.00%)
TGA	0.5	0.8	0.1	225.53	3.29%	570.00	225.54 (3.29%)
TGA	0.6	0.7	0.1	225.53	3.29%	570.00	225.54 (3.29%)
TGA	0.7	0.8	0.0	225.53	3.29%	570.00	225.54 (3.29%)

Table 9 - Results Calculated form Traffic Data of Network in Keelung City

Method	Rate of Match	Preventing Incest	Rate of Mutation	PI	Improvement Percentage	Execution Time (Sec)	PI of TRANSYT-7F
T7F	-	-	-	183.34	-	4.31	183.34 (0)
TGA	0.5	0.8	0.1	156.08	0.1487	570	193.77 (-5.69%)
TGA	0.6	0.7	0.5	154.72	0.1561	570	194.1 (-5.87%)
TGA	0.7	0.8	0	157.4	0.1415	570	193.77 (-5.69%)

The results of practical network case study revealed:

1. Under high traffic flow, converged performance index of Chin-Hua Artery improved less (9.34%), but improved more under medium and low flows (11.16% and 12.95%).

2. Under optimum parameter combination and rate of match 0.5, 0.6, and 0.7, there were little differences among their improvements of converged performance.
3. Within enough long execution time, converge performance index results of TRANSYT-GA were better than TRANSYT-7F and T88, and in the cases, the biggest improvement was 15.61% (network of Keelung City).
4. Within the same converge time with TRANSYT-7F, differences between performance index figured out were that Chin-Hua Road improved 6.37% under low flow, 1.87% under medium flow, and 9.34% under high flow, Sun-Min Artery in Taichung City improved 3.29%, and network of Keelung City improved -5.87%.

5. CONCLUSIONS AND SUGGESTIONS

Through calculations and analyses in this study, the following conclusions are obtained:

1. Through appropriate application, the Genetic Algorithm could solve the problems of network signal timing optimization effectively.
2. Within enough time to calculate, TRANSYT-GA Model established in the study could seek signal timing pattern with lower system performance index (combination of vehicle's number of stop and delay time) than TRANSYT-7F Model.
3. According to the results of artificial network test in this study, we found performance indexes of signal timing pattern figured out from TRANSYT-GA and TRANSYT-7F were approximate when vehicle flow in network was very high or very low.
4. Taking examples from the cases of this study, within the same calculating time with TRANSYT-7F, in performance index of signal timing pattern figured out from simulation case, TRANSYT-GA improved from 16.46% (3x3 artificial network) to -7.25% (3x3 artificial network) than TRANSYT-7F, while performance improvement of practical case was between 9.34% and -5.87%. And, within enough long execution time, in performance index of signal timing pattern figured out from simulation case, TRANSYT-GA improved from 17.6% (3x3 artificial network) to 0.62% (3x3 artificial network), while improvement of practical case was between 15.61% and 3.29%.
5. Aiming at signal timing optimal problem, we found from tests of this study that, it was better to use two-point crossover for chromosomal crossover in the Genetic Algorithm. Converge speeds of one-point crossover and uniform crossover on time axis were slower.
6. In the Genetic Algorithm, population in different rate of match had different combination of optimum preventing incest and probability of gene mutation. When the size of population was 100, parameter combination spreading match rate of optimum converged performance was around 0.5, 0.6, and 0.7, and universally better when rate of match was 0.6.
7. For signal timing pattern optimization, this study defined chromosome fitness as a reversal of performance index's n degree. According to the test results we found it was better when n was 1.
8. K Value of performance index was a relative weighted coefficient of delay time and number of stops. When K was bigger meant the importance of vehicle stops was

higher, while K was smaller meant the importance of delay time was higher. From the test and research in K value's effectiveness to performance index we found when K was less than or equal to 100, the result obtained from TRANSYT-GA was better than TRANSYT-7F, while between 100 and 200, the result of TRANSYT-7F was better. And, when K was bigger than 200, there were little differences between results of TRANSYT-GA and TRANSYT-7F. Generally speaking, K value should set up between 0 and 100, so was the experimental value of TRRL.

9. In TRANSYT-GA optimization model, we not only unitized chromosomal rate of match, crossover, and gene mutation, but also added the approximate concept of annihilation. In process of generational alternations, chromosomes in population died more than half after every n generations, then, produced new chromosomes by stochastic way to make up the size of original population immediately. For the procedure of genetic deduction, the main purpose was to maintain varieties of chromosomes in population, so that population would not deadlock after several generation.
10. Before using the Hill-Climbing method, if we could obtain the initial solution around the highest performance within solving range in advance, TRANSYT-7F could find the optimum solution fast an effectively. Therefore, for several cases in this study, TRANSYT-7F had better calculation efficiency than TRANSYT-GA.

This study also had some suggestions:

1. For signal timing optimization, we only considered common cycle, split, and offset, but did not optimize number of phase and phase sequence. Researchers interested in this problem should take it into consideration in the future.
2. When the Genetic Algorithm was used in generating alternations, genetic deduction of chromosomes in population could progress simultaneously. We suggested to utilize computers with multi-processors of computer to progress in terms of parallel processing while available.
3. The research of the Genetic Algorithm was not so perfect so far. There must be more analysis methods or theories to be raised in the future, at that time, we can apply more effective analysis methods to solve this problem.
4. Parameter analysis of this study adopted single-factor test, so we neglected completely if there were any interactions between factors. We suggested the continuers to adopt other experimental designs to consider the relations between parameters.
5. In the optimization model of this study, fixed parameters are adopted, for example, we gave rate of match, preventing incest, and mutation probability a fixed value, and did not change it in process. It is worth trying to vary parameters in future researches, and it maybe get better results.
6. The sizes of population and continual generations of population were not discussed in this study. Continual researchers can optimize the both or dispose them in terms of varied variables.

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